

Preface

Today, cars include approximately one-third of their value in electric and electronic components, and the mobility paradigm is being transformed toward “the smart driving” concept, with the aim of enhancing the driver experience, improving the safety, supporting the connectivity and automated driving, but also lowering environmental impact.

The engine is only a part of this complex structure of the vehicle.

However, internal combustion engine remains the main source of energy; its function is not different from that of the first prototypes, which is to convert the chemical energy contained in the fuel in mechanical power. This process involves many complex thermo-fluid dynamic phenomena affected by nonlinear dynamics: intake air motion, air–fuel mixture dosage, combustion process itself, knock and misfire occurrence, particulate particle formation, just to cite few of them.

The challenge during all these decades has been to optimize the combustion process in terms of engine efficiency and pollutant emissions reduction, also to comply with the more and more strict governmental rules.

The challenge is still open.

With this work, the authors want to refocus the attention of academic and industrial automotive experts on nonlinear processes in internal combustion engine, analyzing specific nonlinear conditions, providing original modeling description and effective control solutions able to compensate these nonlinear dynamics.

Chapter 1 is aimed at describing the use of Artificial Neural Networks and Expert Systems in engine applications. Artificial intelligence techniques allow to solve highly nonlinear problems offering an alternative and effective way to deal with complex dynamic systems. Air–fuel ratio (AFR) modeling and control is a typical highly nonlinear problem where a huge number of interconnected parameters needs to be considered and controlled (amount of fuel injected, residual gas fraction, wall wetting are some of the parameters that have to be processed). In this context, we propose a neural network and fuzzy logic approach for AFR modeling and control.

In Chap. 2, advanced non-interfering diagnostics based on optical spectroscopy are presented. Optical diagnostics allow to take a look in what really happens in the

cylinder in terms of flame propagation, gas turbulences, and pollutant formation. In other words, most of the phenomena occurring during the combustion process. The evaluation of these nonlinear phenomena is the key point to design effective control solutions able to optimize engine combustion in terms of engine power, efficiency, and emissions.

Nowadays, great attention is paid to the impact of particulate matter (PM) emitted from vehicles on the environment and, in turn, to the negative effects that it has on human health. Pollutant particles are classified according their diameters in micron (PM10, PM2.5, etc.); smaller the particles are, more dangerous for human health they are as they penetrate more easily the cell membranes. The chemical nature of the emitted particles as well as the number and size depends on engine type and its operating conditions. In Chap. 3, the authors deal with the particulate emission reduction problem, suggesting a real-time approach to model the number and size of emitted particles.

The parameter widely considered as the most important for diagnosis of the combustion process in internal combustion engines is the cylinder pressure. This signal represents, in fact, the most direct signal available for engine control. However, in-cylinder pressure direct measure involves an intrusive approach to the cylinder using expensive sensors and a special mounting process. For this reason, several alternative methods for combustion diagnosis have been suggested in literature. In Chap. 4, we propose a method for advanced and non-intrusive combustion diagnosis using the vibration signal produced by the combustion process on the engine block. Real-time engine control architectures that use this signal are also investigated.

Recently, more robust and cost-effective in-cylinder sensors have been developed, and their usage in mass-produced vehicles now appears more feasible. These new types of pressure transducers are generally integrated in the glow plugs, in the spark plugs, or into the injector valves. Chapter 5 provides an overview of the main applications of cylinder pressure signal in engine modeling and control.

In Chap. 6, the nonlinear phenomena correlated with the injection process in GDI engines are analyzed. A complete description of the injector nonlinear dynamics is provided, and an effective compensation is proposed.

Latest emission regulations, in fact, strongly push toward a reduction of fuel consumption in order to reduce CO₂ emissions because of their effect on global warming. Gasoline direct injection engines, together with fully electric and hybrid vehicles, are the best candidate to satisfy the imposed limits. GDI engines, in fact, can work in stratified operations allowing stable combustions with ultra-lean mixtures that allow a strong reduction of toxic emission coupled with fuel consumption reduction. GDI stratified operation needs the use of multiple fuel injections, splitting the quantity of injected fuel into several and shorter shots in order to reduce the cylinder wall impingement.

However, small injections force solenoid injectors to work in *ballistic* mode, i.e., the injection pulse width is cutoff before the valve fully lifts up, causing a highly nonlinear correlation between electrical command pulse width and the actual

amount of injected fuel. We present a close-loop control able to manage and compensate the ballistic behavior.

We wish the material collected in this Brief can stimulate the interest of young undergraduate and graduate students, researchers both academic and of industry pushing them to develop research projects exploiting nonlinear dynamic problems in combustion engines.

To conclude, we would like to thank all the colleagues that gave their fundamental contribution in the achievement of the results presented in the Brief.

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Modeling and Control

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